A multisensor mine detector for peacekeeping - Improved Landmine Detector Concept (ILDC)

John E. McFee

Design Team Leader,
Improved Landmine Detector Concept (ILDC) Project

Major Al Carruthers

Project Manager, ILDC Project
Defence Research Establishment Suffield,
Box 4000, Medicine Hat, AB, Canada, T1A 8K6

ABSTRACT

The Improved Landmine Detector Concept (ILDC) Project was initiated in Autumn 1994 to develop a prototype vehicle mounted mine detector for low metal content and nonmetallic mines for a peacekeeping role on roads. The system will consist of a teleoperated vehicle carrying a highly sensitive electromagnetic induction (EMI) detector, an infrared imager (IR), ground probing radar (GPR), and a thermal neutron activation (TNA) detector for confirmation. The IR, EMI and TNA detectors have been under test since 1995 and the GPR will be received in June 1996. Results of performance trials of the individual detectors are discussed. Various design configurations and their tradeoffs are discussed. Fusion of data from the detectors to reduce false alarm rate and increase probability of detection, a key element to the success of the system, is discussed. An advanced development model of the system is expected to be complete by Spring 1997.

Keywords: mine detection, multisensor data fusion, peacekeeping, electromagnetic induction, infrared, ground probing radar, thermal neutron activation, trace explosives detection

1. INTRODUCTION

For over 40 years, there has been an extensive world-wide research effort directed at the detection of mines. Fig. 1 illustrates this by showing the approximate research time lines for a number of detection technologies applied to mine detection. Although the effort has encompassed a wide range of technologies and in spite of the expenditure of many billions of dollars, there exists to date no viable detector for buried nonmetallic mines.

One of the chief reasons for this lack of success has been the stringent constraints that have been imposed on such detectors by the need to operate in a high intensity battlefield environment. These constraints mandate a high probability of detection (PD) together with a low false alarm rate (FAR), for the detection of all types and sizes of mines, at high speed without stopping, during all environmental conditions and on all types of terrain. In general, it seems that attempting to satisfy all of these requirements leads to solutions involving great technological complexity with the attendant high risk and expense. This is borne out in that extensive research has led to numerous detectors that each fulfil a few of these requirements, but not simultaneously all of them.

In July 1993, the Chief of the Canadian Defence Staff directed that a high priority be placed within the department to determine means to reduce the threat of nonmetallic land mines. In response, a study was initiated by the Research and Development Branch, CRAD, to identify potential areas of research in detection, neutralization and protection that would be suitable for Canada. The study combined results of previous analyses and mine detection research conducted since 1975 by the Department[1,2] and analyses of the latest advances in technologies relevant to mine detection. The final report[3] recommended that Canada should select a research niche that is relevant to Canadian Forces operational requirements but which had relaxed constraints which might lead to a tractable solution. It went on to state that such a niche indeed existed, namely clearance of mines on roads in peacekeeping.

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In peacekeeping, low speed ($\sim 1 - 5$ km/hr) is acceptable. Restricting operation to roads greatly simplifies problems with mobility and sensor motion and placement. There is no requirement to detect completely nonmetallic mines. Such mines comprise a very small fraction of the total population and missing them is deemed an acceptable risk. It is assumed that a protection vehicle precedes the detector vehicle to remove small antipersonnel mines and hence the detection of such small mines is not required. Usually, there is some flexibility in the choice of operating time and weather. Together, these relaxed requirements greatly increase the likelihood of success.

The Improved Landmine Detector Concept (ILDC) Project was initiated in Autumn 1994 to develop a prototype vehicle mounted mine detector for low metal content and nonmetallic mines for a peacekeeping role on roads. The Defence Research Establishment Suffield (DRES) is the lead laboratory, with assistance from DRE Ottawa (DREO) and DRE Valcartier (DREV). An advanced development model of the system will be complete and tested by Spring 1997.

2. THE SYSTEM CONCEPT

The philosophy behind the ILDC system is to use detector technologies that have been previously tried for mine detection but have been discarded for the high intensity conflict role. The detectors initially considered were chosen on the basis of previous research[1-3] and the full criteria for selection of these technologies are detailed in.[3] Among the most important criteria were the potential for moderately high PD of a mine, robustness, technical maturity and relative inexpensiveness. If a technology was found to satisfy these four criteria, it was likely to have an excessively high FAR. Thus the selected technologies were required to measure properties of the mine or mine site that are generally uncorrelated in normal ground but are simultaneously detectable when a mine is present. This allows data fusion to potentially make the system FAR much lower and the PD higher than that of an individual detector. In addition, since it was recognized that each detector would not function well in certain environmental conditions or times of day, technologies were selected to complement each other and minimize times for which more than one technology was inoperative.

The system concept is shown in Fig. 2. It consists of a teleoperated vehicle carrying a highly sensitive electromagnetic induction (EMI) detector, an infrared imager (IR), ground probing radar (GPR), and a thermal neutron activation (TNA) detector for confirmation. Data fusion combines the detector outputs to reduce the false alarm rate to acceptable levels. It is assumed that a protection vehicle precedes the detector vehicle to remove small antipersonnel mines (and possibly precondition the road) and that the pressure and electromagnetic signature of the detector vehicle are insufficient to activate antitank mines.

3. DETECTORS

Four mine detection sensors (detectors) are used in the ILDC system. EMI, IR and GPR are scanning technologies that detect properties associated with mines while the vehicle moves. The TNA is called a confirmation technology. It operates with the vehicle stationary and can confirm the presence of explosives.

Trace explosive detection (TED) was initially investigated as a possible backup confirmation technology to TNA. Trials were conducted at DRES in December 1994 using detectors from three Canadian companies. CPAD Technologies used an ion mobility spectrometer/gas chromatograph (IMS/GC) system with a sophisticated automatic real-time ($\sim$ 20 seconds/sample) vacuum soil sampling system. Barringer Research used an ion mobility spectrometer (IMS) and Scintrex employed a pyrolysis/electrochemical detector (PED). Barringer and Scintrex collected soil by a variety of techniques such as vacuum cleaners and swipes and analysed the samples off-line ($\sim$ few minute/sample), after some very simple wet chemistry. Vapour samples in air were also collected. The double blind experiment was performed in cold dry conditions. Sixteen mines of various types, some empty holes and some cartridge casings were buried at operational depths. Some had been buried for a month, others for a few days. Results showed that vapour detection in air was ineffective. For the soil sampling, overall detection rates were no higher than about 65%. False alarm rates were high but difficult to quantify due to the small number of non-mine sites tested. Serious problems with cross contamination were encountered and may be a limiting factor in the technology. In practice, lingering explosive vapours and particulates, which settle out during or after a conflict, might produce a diffuse background signal. The trials verified that personnel who routinely handle mines are highly contaminated with explosives and leave readily detectable explosive residue everywhere they travel. These effects could prohibit mine localization to better than several meters or more. Because of these problems, TED was dropped from consideration for ILDC, but continues as a small R&D subprogram.

3.1. Electromagnetic Induction

Electromagnetic induction consists of exposing a conductive object to a time-varying magnetic field (usually produced by a time-varying electric current in a loop of wire) and detecting (usually by a second loop of wire) the secondary magnetic field produced by eddy currents induced in the object (Fig. 3). The large variety of metal detectors available in the market use some implementation of this principle. Since the technique detects only metal, it is useless for detection of purely nonmetallic mines. However, it has been estimated that well in excess of 90% of all land mines, including so-called "plastic" or "nonmetallic" mines, contain one or more small metal parts in the fuze. Hand-held instruments capable of detecting the metal in most mines are already commercially available, but there are as yet no high sensitivity wide scan instruments capable of being vehicle mounted. The false alarm rate for such a sensitive system will be a function of the geomagnetic properties of the scanned area as well as the presence of metallic debris and will thus be highly scenario dependent. Initial indications are, as expected, that the nuisance alarm rate will be high.

The EMI detector used in ILDC was developed under contract by Schiebel Systems Ltd., Canada. It consists of 24 overlapping transmit/receive coil pairs which sweep an effective width of 3m (Fig. 4). The system underwent testing at DRES in December 1995. Typical data are shown in Fig. 5 which emphasize the need for additional independent detectors to reduce the false alarm rate. Although apparently more sensitive than the hand-held Schiebel AN 19/2, problems with long term drift and general system reliability have still to be corrected. The solutions to these problems are thought to be straightforward and the revised detector is expected to be complete by May 1996. Work is underway on detection algorithms for the array. Time series and image-based algorithms are both under study. Both approaches rely on the correlation between adjacent coil pairs to increase information abaout the strength and extent of each detection. Some promising algorithms have already been identified, although considerable refinement is necessary.

3.2. Infrared Imaging

The principle of operation of infrared detection is illustrated in Fig. 6. The change, compared to undisturbed soil, in spectrum or intensity of infrared radiation emitted by the soil over a buried mine is measured. Radiation is typically measured in the 3-5 or 9-14 μm wavebands or both simultaneously. The change in radiation is usually quoted as an equivalent change in surface temperature. The cause of the radiation change is the alteration of the heat flow by the mine and disturbed soil and the change in surface emissivity of the disturbed soil. The latter change may disappear after a period of time. There will be a diurnal periodicity in the apparent surface temperature difference between the soil over the mine and undisturbed soil with at least two time windows during which there is no measurable difference. Mines buried below a certain depth (roughly 0.1 - 0.2 m) can have no effect on surface temperature, but the soil disturbance still can. Because numerous phenomena can generate temperature differences similar to that of a buried mine, it is necessary to obtain an infrared image. Imagers of sufficient temperature resolution (at least 0.1 °C) and spatial resolution to detect the anomalies due to a mine are commercially available from numerous sources.

Imaging experiments at DRES, DREV and CFS Wainwright since December 1994 using an AGEMA 1000 IR camera (9-14 μm) mounted on a surrogate vehicle (Figs. 7, 8) have shown that the presence of a mine is detectable for at least several months after the mine has been buried. Detection rates vary from 20% to 100% and are a function of soil type and compaction, moisture, shadow, time of day and diurnal thermal cycling (Fig. 9). The false alarm rate is between roughly 0.1 and 0.8 per 10 meters of forward advance for a 3m sweep width.

To minimize technical risk, target identification will be done by an observer without benefit of automatic target recognition (ATR) algorithms. To reduce observer fatigue and improve PD, dynamic range compression and contrast enhancement will be done automatically prior to presenting the images to the observer. Compression is necessary since the imager has a large temperature range (4096 levels), whereas the scene has a much smaller range of temperatures (<256 levels) with an effective baseline that varies with time and conditions. Dynamic range compression determines the portion of the range that contains the scene temperature information and provides only that range for display to the observer. Simple statistical-based compression methods should be sufficient to handle the problem. A study was conducted[4] to determine the most suitable algorithms for contrast enhancement. A large number of single frame global and local algorithms, multiframe algorithms and multiresolution methods were investigated. For most of the images, a simple piece-wise linear histogram transformation proved effective. Some algorithms, such as that due to Devries, can automatically perform dynamic range compression and contrast enhancement at the same time. If time permits, ATR algorithms, including the hierarchical algorithm developed for remote minefield detection,[5] will be tested on the infrared imagery.

Since the performance of IR is very dependent on ambient environmental conditions, such as temperature, precipitation history and soil type, it is important for data fusion to be able to predict performance in advance of operation. The relationship of performance to such measurable environmental parameters is, however, difficult to interpret. An alternative approach is to monitor the subsurface temperature gradient, which turns out to be well correlated with apparent temperature contrast between mined and non-mined sites. This is described more fully in.[6]

3.3. Ground Probing Radar

A ground probing radar operates by transmitting electromagnetic energy, usually in the hundreds of MHz to several GHz range, into the ground using a suitable waveform. A large part of this signal is reflected back to the radar receiver from the ground-air interface (Fig. 10). The remaining signal that penetrates the ground is attenuated due to absorption losses and is scattered as it propagates in the soil due to the non-uniformity of its electromagnetic properties (such as dielectric constant, conductivity). The signal reaching a target such as a mine or a rock, which appears as an isolated discontinuity in the soil electromagnetic properties, is scattered by it and part of the signal propagates back to the GPR receiver in the air, again being attenuated and scattered. The attenuation reduces the amount of signal to and from the target and the scattering produces clutter which causes false alarms. Signal attenuation is a strong function of soil moisture content and signal frequency. Clutter depends on the degree and detailed characteristics of nonhomogeneity of electromagnetic properties of soil. The signal scattered by the target depends on factors such as the size, shape and orientation of the target, frequency of the radar and the difference in electromagnetic properties between the target and the host medium.

GPR has been extensively researched for over two decades for the detection of buried mines. Active systems of various designs (e.g., impulse, continuous wave, frequency modulated continuous wave, step frequency, separated aperture or waveguide beyond cutoff, balanced bridge, etc.) have been tried. These systems can detect some nonmetallic buried mines under certain restricted conditions, but strong and variable soil clutter, low target contrast and nuisance targets such as rocks and soil inhomogeneities have made overall performance poor. Among the reasons for this poor performance is that most GPR systems used for mine detection have been adaptations of ones designed for geophysical applications and as such are not optimized for mine detection. For example, most are intended for deep penetration and so use low frequencies. Mines are not deeply buried and clutter elimination is essential. The latter requires high frequencies for good spatial resolution in order to image areas of strong signal return.

Some recent research on GPR has specifically addressed the problem of mine detection, rather than treating it as another application of conventional geophysical GPR R&D. A few prototype systems are being developed that have potential for mine detection, although most are not commercially available. Only one GPR was deemed to be both potentially suitable for nonmetallic mine detection and to be commercially available. The system, manufactured by ELTA Electronics, Israel, has been under development for several years for the express purpose of vehicle mounted mine detection. The radar (Fig. 11) is continuous wave, frequency modulated and ultra-wide band (1-3 Ghz). The existing system has a 2 m wide antenna consisting of 24 elements, mounted 70 cm above the ground surface. It is claimed to be able to operate at speeds up to 4 km/hr and to detect mines from above ground surface to 30 cm depth for antitank mines.

Experiments were conducted by DRES, DREO and ELTA personnel in Israel in June 1995 using the ELTA GPR. Seven mine types and three sizes of urethane mine simulants were buried in three different test tracks. One track consisted of loose sand, with rocks and industrial debris. The second consisted of packed sand and silt, with rocks and industrial debris. The third had an uneven broken asphalt surface. The weather was hot and dry. The average PD for the mines was 86.6% (103/119) with an average FAR of 1.5 per 10 m of forward advance for a 2 m wide antenna array. The simulants were less detectable, having an average PD of 63.8% (67/105) with an average FAR of 1.1 per 10 m. There are two reasons for the poorer performance for the simulants. First, the simulants were intended for thermal IR detection studies and as such the dielectric constant was much closer to that of soil and much more uniform throughout than is typical of mines. Second, the simulant signature features were not specifically included in the ELTA classification data base.

The experiments revealed that the ELTA GPR has some limitations. Its ability to detect small AP mines is poor. This is not a serious problem since it is assumed that a protection vehicle precedes the detector vehicle to remove AP mines. The system will also incorrectly classify some detected objects, such as rocks, as mines if their shape and size roughly matches that of an AT mine. Nevertheless, based on these experiments and additional analysis, a 3 m wide ELTA GPR, with some additional modifications, has been ordered and delivery is expected in June 1996. A

planned loan of the existing ELTA GPR in Spring 1996 will allow collection of sufficient data to allow finalizing the data fusion methodology.

3.4. Thermal Neutron Activation

Explosives have a large percentage by weight of nitrogen (~ 17 to 38%), whereas soils and materials in soil (even heavily fertilized soil) have a much smaller percentage (between 0 and 0.1%). In thermal neutron activation detection, a slow (thermal) neutron from a radioactive source or electronic neutron generator excites a nitrogen-14 nucleus and causes it to emit characteristic gamma rays (Fig. 12). One of the nitrogen gamma rays (10.8 MeV) is well isolated from background gammas, with the exception of a 10.6 MeV silicon gamma, whose intensity is negligible in comparison.

The TNA detector used in ILDC was planned as a confirmation tool which would be moved over a suspected target and dwell there for a period of between 10 seconds to a few minutes. This allows the system to be made much more compact and less expensive than a full width scanning system that would be required if no other detectors were available for data fusion. The system was designed to ILDC specifications by SAIC Canada with Bubble Technologies Inc. (BTI) acting as a major subcontractor. It uses a Californium-252 source and a ring of four high sensitivity, low energy resolution NaI(Tl) detectors and specialized BTI detection electronics which is capable of handling the high count rates encountered (Fig. 13). The detector assembly weight is less than 300 kg.

The TNA detector was delivered in September 1995 and preliminary testing on real landmines took place at DRES in November 1995. Test results are summarized in Fig. 14. The experiments illustrated that the confirmation of antitank and large antipersonnel mines is feasible in the peacekeeping role, although confirmation of small antipersonnel mines is not possible in a practical time period. The experiments suggested a number of possible improvements that could increase sensitivity, thereby reducing counting time and/or detector weight, and reduce electronic complexity. A number of these changes are being implemented by SAIC Canada and BTI. The improved detector will be ready for integration to the system by June 1996.

4. CONFIGURATION

The configuration of the system (the physical layout of the components), the method of operation, the choice of data fusion strategy and the overall system performance all interact with one another. Fixing one of the above items has an impact on the others. This implies that there are an enormous number of possible configurations. Space does not permit a detailed discussion of all the factors which were considered in choosing the final configuration, but a few of the more critical ones will be mentioned.

1. Number of vehicles. A second vehicle carrying the confirmation detector allows the lead vehicle with the scanning detectors to travel at higher average speeds. However, additional operators may be required, unless the vehicles are tethered, and logistics is more complicated. Sensor data co-registration is much more difficult with two vehicles.

2. Order of sensors. There are numerous tradeoffs here. It is preferrable to place scanning sensors with lower data rates ahead of those with higher rates, allowing the former to cue the latter. If the lead sensor contacts the ground, as the current configuration of the EMI sensor dictates, then the road may be disturbed in the IR field of view, which can temporarily defeat the IR imager. If this happens or if the lead sensor blocks the optimum field of view of the IR imager, then the field of view must be moved ahead of the lead sensor to a position which may be nonoptimal.

3. Sensor separation. Sensors should be close together to reduce data coregistration problems and minimize the overall length of the vehicle to improve manoeuvrability. However, there must be a minimum metal-free zone around the EMI detector and there must be sufficient distance from the scanning sensors to the confirmation detector to allow the vehicle to stop with the mine in the operational zone of the confirmation detector.

4. Confirmation detector manipulator. A raster scan system must be custom made, but may make sensor placement simple. A robotic arm may be commercially available but is expensive and requires sophisticated control software. A novel approach, currently under consideration, is an independently mobile platform containing the confirmation detector which is electronically tethered to the main detector vehicle and receives instructions from an operator via the detector vehicle.

5. Modes of Detection. The system could either move continuously down the road, stopping only to use the confirmation detector or employ a "stop-and-go" method. In the latter, the detector vehicle is moved into position and an area ahead of the vehicle is scanned using the IR imager. Then the vehicle is moved ahead a fixed distance and a second sensor, either the EMI or GPR sensor, scans the previous area, while the IR scans a new area. As the vehicle continues to move ahead in increments, a new sensor moves into the area and so after four increments, all four sensors have interrogated the area. Such an approach eases some of the data fusion requirements. Although it is slow, in high FAR areas this imposes no penalty.

6. Choice of vehicles. A detailed study of the performance, weight and power envelopes of the teleoperated vehicle revealed that there were no commercially-built vehicles, either teleoperated by the manufacturer or which could be readily teleoperated, which could meet the project requirements. It was thus decided to design and manufacture under contract a custom vehicle.

After weighing the numerous factors, a preferred configuration was selected (Fig. 2). The lead sensor platform may be steerable, independent of the scanning detector vehicle. A steerable sensor platform is required to maintain an effective sensor sweep width of 3 m if the combined scanning sensor along-track separation exceeds a certain value. At present, it appears that it may be possible to place the sensors such that steerability is not necessary, thus substantially reducing system complexity. A forward-looking visible wavelength (VIS) imager acts as both a camera for steering the vehicle and, at times, an independent mine detector. The TNA sensor, being relatively heavy, has been put on an attached slave vehicle to keep the lead vehicle ground pressure less than the activation pressure of an antitank mine. A second VIS camera monitors the workspace of the confirmation detector to ease positioning of the sensor and to augment detection. A marking system places a mark over positions of potential targets that have been validated by the confirmation detector. Both continuous and stop-and-go methods will be used, depending on the false alarm rate encountered in a particular situation.

5. DATA FUSION

A key element to the success of a multi-sensor mine detection system is the fusion of data from the various detectors and position sensing systems. This is a complex task, which has been mentioned frequently in connection with a mine detector systems in the past, but has not been truly incorporated in any of them.

Before the actual data fusion can take place, the detections from the different sensors must be co-registered in a common coordinate system. This is not a trivial task, since the IR and VIS cameras are imagers which are pointed at a significant angle from nadir, while the GPR and EMI detectors are non-imaging sensors which are close to the ground and which are essentially down-looking. Co-registration is achieved by first projecting the location of the detection from the sensor coordinate system to a world coordinate system. The position of the detection is tracked in the world system from the initial detector through the fields of view of the other detectors. Within each subsequent detector's field of view, new detections (tracks) can be added or combined with existing tracks (depending on the data fusion scheme). For the co-registration/tracking to succeed, an accurate navigation package is required. Differential GPS, although attractive, cannot be relied on exclusively because of reliability problems in heavily treed or urban areas. In addition, tracking filters are required which incorporate a realistic dynamic model, since simple models, such as a flat earth approximation, are not likely to be valid in practical situations. Sensor co-registration may be substantially simplified when using the stop-and-go method.

Each sensor measures one or more physical properties, each of which has a range of values including those of landmines. When the measured property value(s) fall within the appropriate range, a detection by the sensor is said to occur. The two simplest methods of data fusion combine sensor detections in series (logical AND) or in parallel (logical OR). Both have advantages and disadvantages. Methods which attempt to retain the strengths of the two, while eliminating their weaknesses are being investigated. One method under consideration is loosely related to Klein's voting fusion scheme,[7] which uses Boolean algebra to combine detections, based on the confidence levels for each detection. The confidence level for a detection by a specific detector is a function of the detector condition (signal strength, environmental status, etc.), as well as what other detectors have registered a detection and with what confidence. A detailed discussion of the method is beyond the scope of this paper. Both totally automated data fusion and combined automated/operator-in-the-loop fusion are under investigation.

Implicitly necessary in the described data fusion method is the ability to predict the confidence of detection of a mine property by each sensor, given a certain response, before commencing the mine detection exercise. The simplest

approach is to monitor the background signal for each sensor, as well as ambient conditions appropriate to the sensor. The latter may include, for example, soil type for an EMI, GPR or IR sensor or diurnal air temperature profiles for an IR sensor. Another approach is to make measurements of unarmed mines or surrogates deliberately buried in a test section of road prior to starting the actual mine detection. A third approach is monitor time varying parameters which are well correlated with detector performance, but are not simply related to environmental parameters. An example, as previously mentioned, is measurement of soil temperature gradient profiles, either locally or at a remote site, for IR detection.

6. CONCLUSIONS

The ILDC project is past the half way point and progress to date has been good. The required sensor prototypes have been built and, although further improvements and testing are still being done, finalized detectors are expected by June 1996. A strong effort is now being made toward the sensor data co-registration and fusion. The custom teleoperated vehicle design is nearing completion and construction should commence soon. Although concept and preliminary design were done by the Department of National Defence, it is planned to transfer the technology to a Canadian company who will complete the final design and construction and provide long term customer support. As a first step, a system integration plan has been developed in conjunction with the prime contractor, Computing Devices of Canada. The system is expected to be complete by late Autumn 1996 and testing will be completed by April 1997.

7. ACKNOWLEDGMENTS

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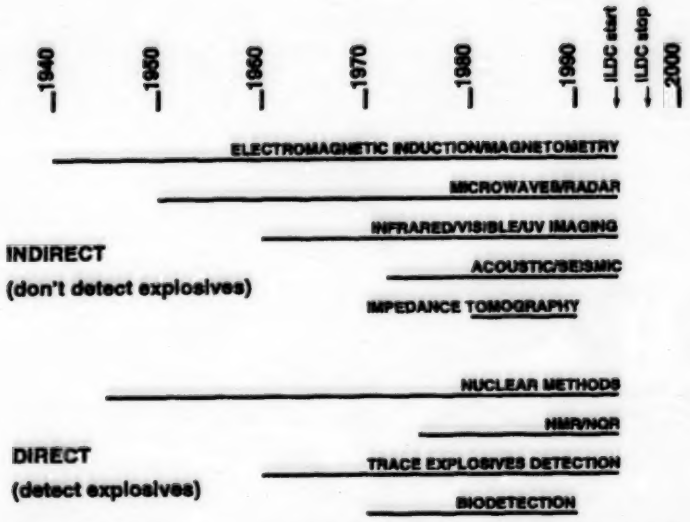

Figure 1. Time lines of world-wide research on mine detection technologies up to the start of the ILDC Project.

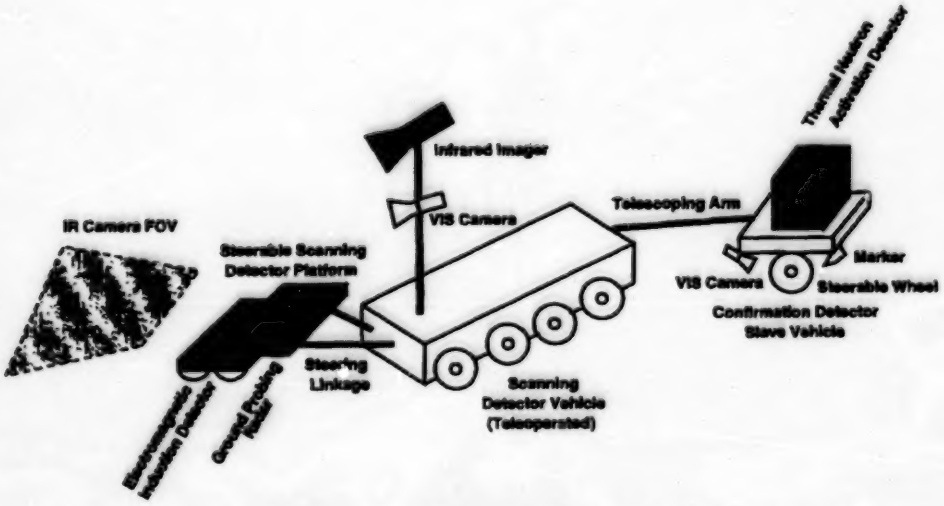

Figure 2. Improved Landmine Detector Concept system.

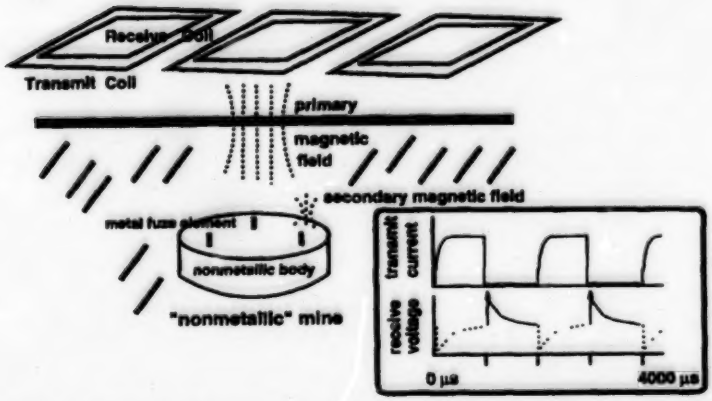

Figure 3. Principle of operation of electromagnetic induction detection of buried mines.

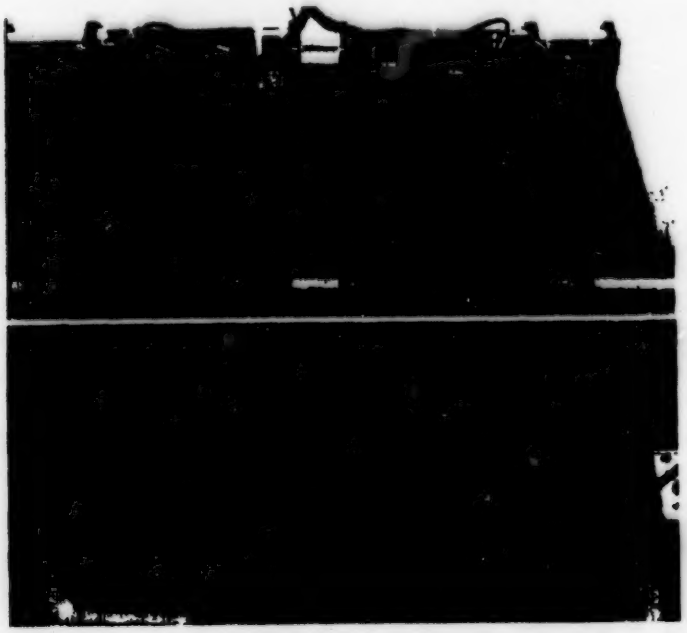

Figure 4. The Schiebel electromagnetic induction minimum metal mine detector. At top is shown a portion of the coil array with overlapping transmit/receive coil pairs. The electronics module is shown at the bottom.

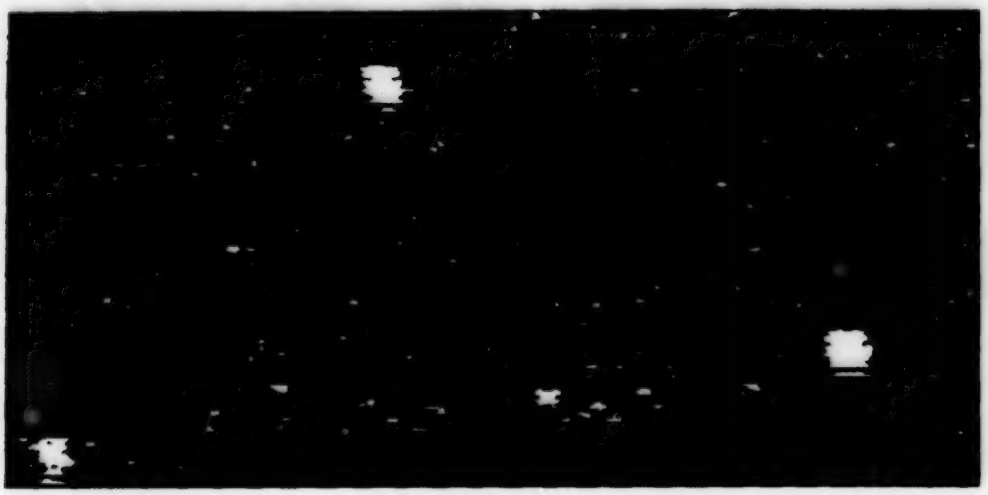

Figure 5. Data taken with the Schiebel electromagnetic induction mine detector on a dirt road at DRES. Each of the 9 wide strips represents the full width of the array as the detector moves along the road at uniform speed. Strongly positive signals are white, strongly negative signals are black. A number of mines are detected, as well as a number of nuisance items and false alarms.

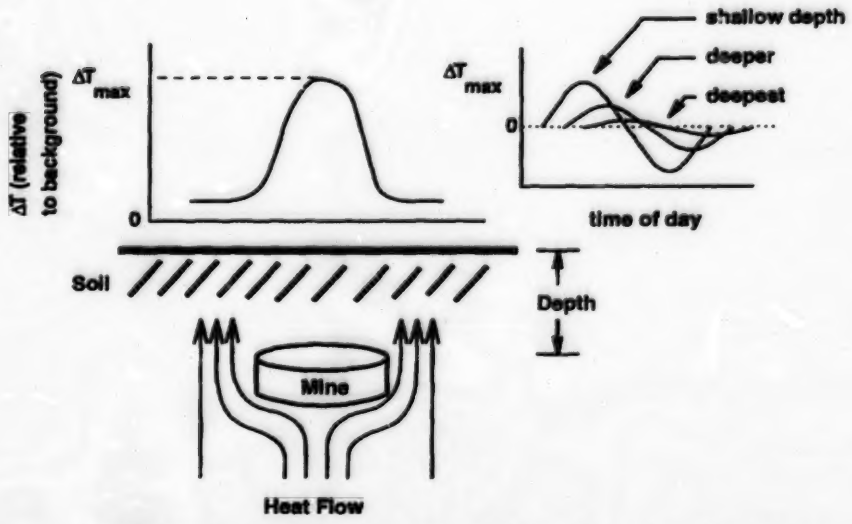

Figure 6. Principle of operation of infrared detection of buried mines.

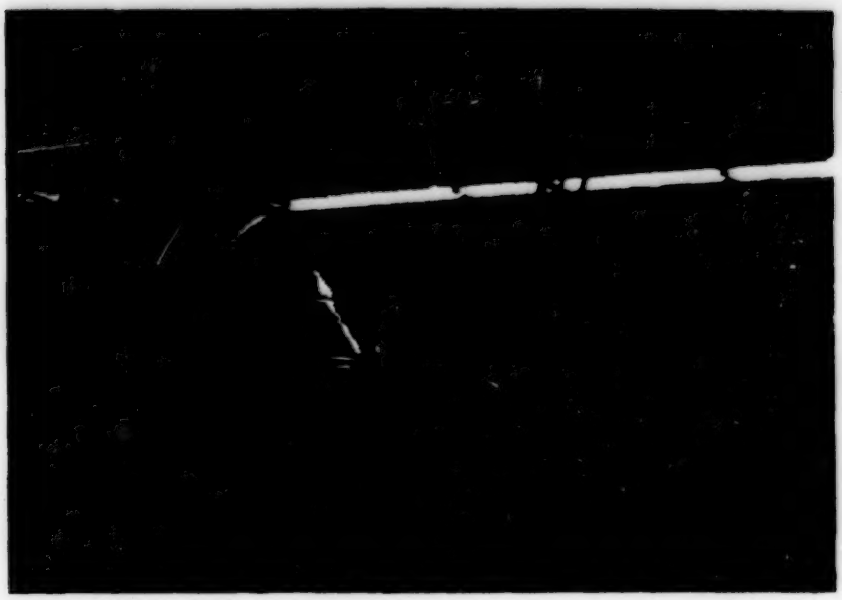

Figure 7. Surrogate vehicle with forward-looking IR camera. Computer for display and image processing can be seen in front of the passenger door.

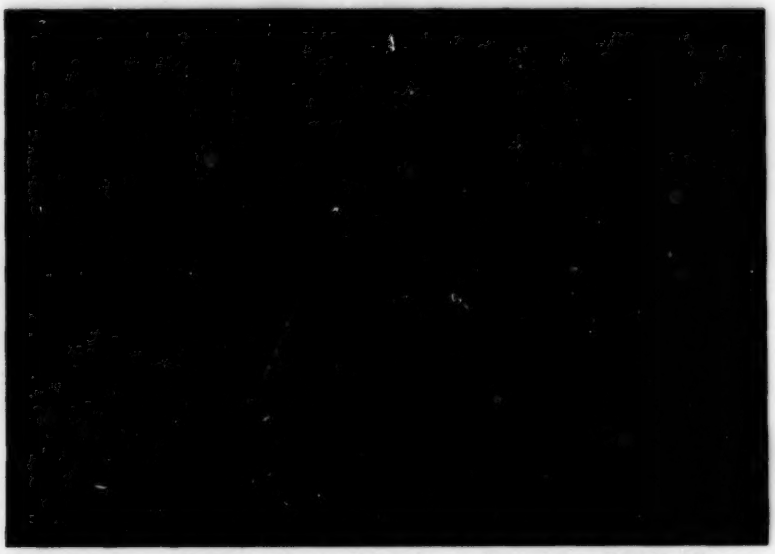

Figure 8. Typical image of an antipersonnel mine buried in a dirt road at DRES. Mine appears as a white blob at the lower center of the image. Note various blobs that could be potential false alarms.

	NIGHT TIME		
	Probability of Detection		False Alarm Rate (/10m)
	Antitank (%)	Antipersonnel (%)	
Route 1	63-100	25-75	0.13-0.59
Route 2	38-83	20-45	0.20-0.24
	DAY TIME		
	Probability of Detection		False Alarm Rate (/10m)
	Antitank (%)	Antipersonnel (%)	
Route 1	55-80	21-75	0.43-0.77
Route 2	46-76	0-45	0.37-0.78

Figure 9. Summary of the results of the July 1995 thermal IR mine detection trials at CFB Wainwright.

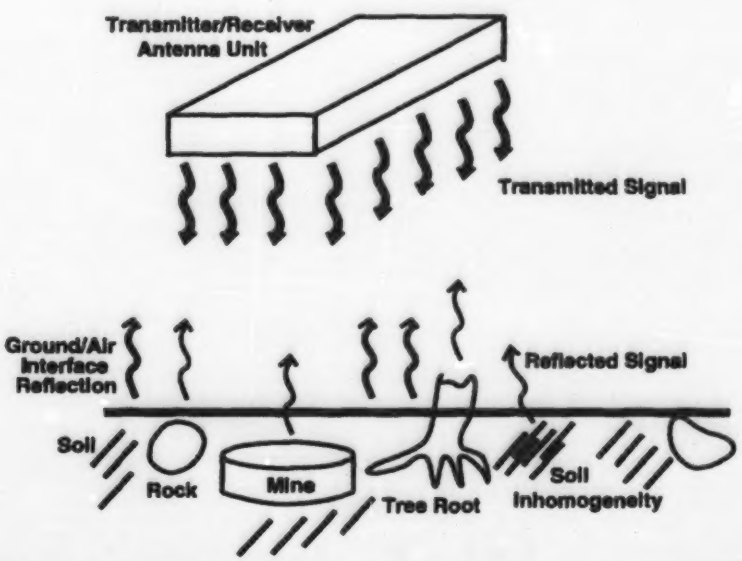

Figure 10. Principle of operation of ground probing radar detection of buried mines.

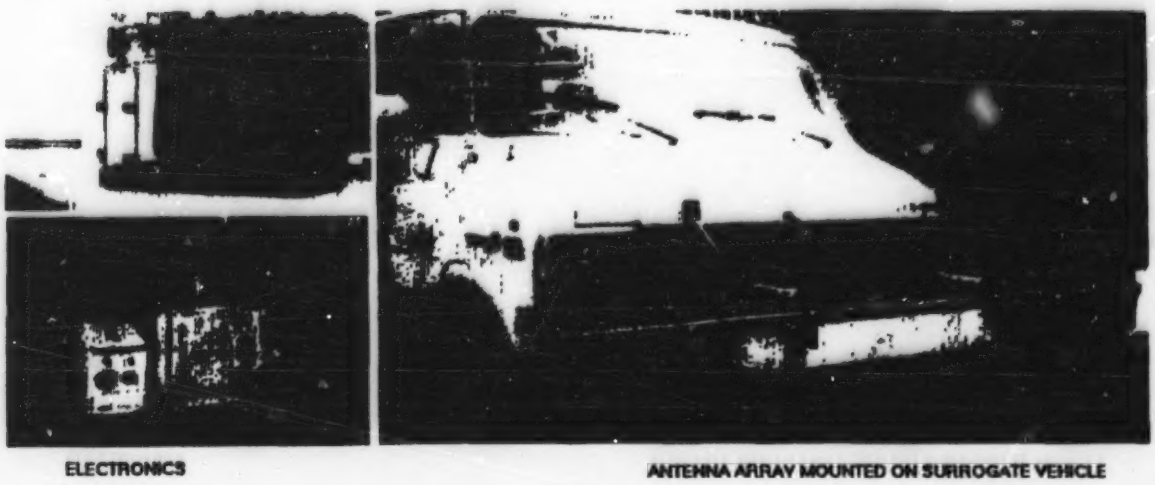

Figure 11. Electronics (left) and antenna array (right) of present ELTA ground probing radar.

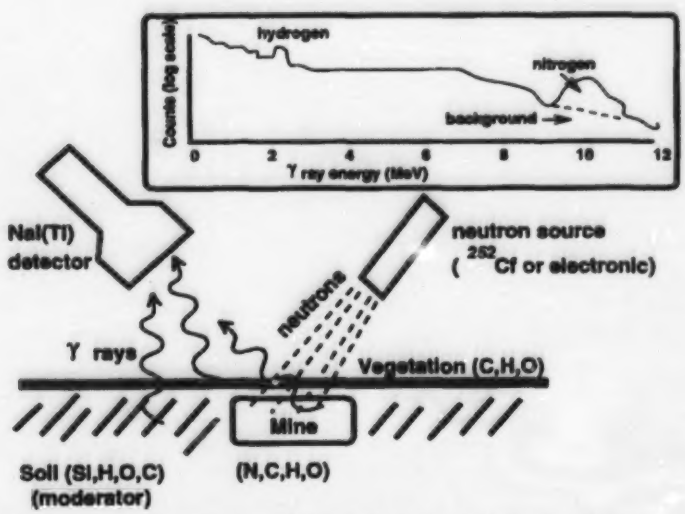

Figure 12. Principle of operation of thermal neutron activation detection of buried mines.

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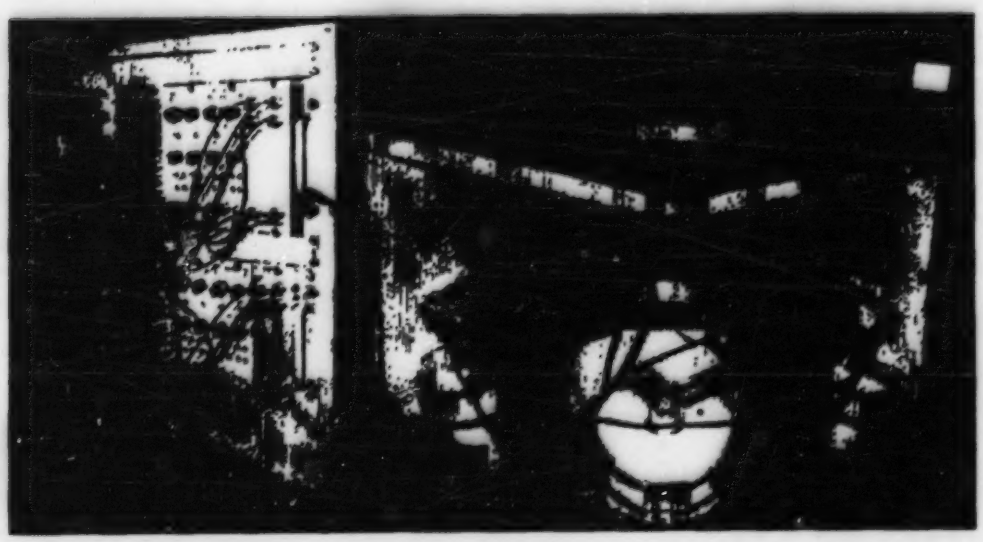

Figure 13. Thermal neutron activation detector electronics (left) and sensor head (right).

MINE TYPE	NITROGEN MASS (KG)	DEPTH (CM)	MINIMUM COUNT TIME FOR P_D = 93 % PRESENT BACKGROUND (N_B) ASPHALT	GRAVEL	SAND	N_B / 4 SAND
M15	3.0 - 3.9	5	-	-	4 s	1.4 s
M15	3.0 - 3.9	30	577 s *	154 s	165 s	44 s
TMA3	1.20	10	26 s	35 s	10 s	3 s
1/2 TMA3	0.60	5	-	-	38 s	11 s
M16	0.10	0	413 s	396 s	-	-
M16	0.10	5	364 s	-	273 s	74 s

* Suspect value since detector was likely not over mine during measurement
\- Value not measured

Figure 14. Summary of detection times for preliminary TNA tests.